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Pavements for Modern Traffic

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PAVEMENTS FOR MODERN TRAFFIC

BY

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I recommend that the thesis prepared under my supervision by RALPH GERALD PETERSON entitled Pavements for Modern Traffic be approved as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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INTRODUCTION.

Advantages of Good Roads.

Good roads are essential to every civilized country both for social and economic reasons. The benefits derived from good roads are so numerous that only a few of the principal ones will be reviewed.

The whole country is greatly benefited financially by good roads. The cost of hauling goods per ton mile is decreased. Transportation is made possible throughout the year. A wider choice is given as to the place of marketing, and higher prices may be obtained for goods. Railroad traffic is equalized throughout the year, as goods may be hauled to station points at any season of the year. This also tends to equalize mercantile business between different seasons of the year.

The social benefits derived from good roads are of much importance. Members of rural communities are more easily brought together, and they may enjoy the advantage of an efficient mail delivery which greatly improves the intellectual condition of the population. Large attendance of rural schools is made possible, and the number of schools may be decreased, thereby promoting greater efficiency of our educational system.

All of these advantages are of prime importance for the development and growth of our country, but there is another claim which may be urged for the improvement of our highways. We are living in an age where the development of science and engineering have been very rapid. Improvements have been made on everything that tends to better the condition of the people, and bring

every convenience possible. We have electric lights, running water, telephones, and almost everything to be desired in our dwelling places - both urban and rural. Now, if we wish to travel about the country over our highways, should not we also expect to find improvements made for our benefit and convenience? No pleasure can be derived in driving either a horse or an automobile over a road which has not been improved or properly maintained; but if all of our roads were what might be called good roads, what a pleasure it would be, both to the farmer and the city man, to be able to travel from place to place over a perfectly smooth and well maintained highway. The people of this country spend millions of dollars every year for personal pleasures and conveniences - why not for good roads which would furnish pleasure and convenience, and at the same time, they would be a great benefit to the whole country in other ways.

History of Roads.

Good roads are by no means a modern convenience. Before the time of the Romans roadways were merely the tracks worn by the feet of pedestrians and the wheels of vehicular traffic. The first known good road was built by the Romans in 312 B.C., and was called the Appian Way. This road was constructed of four different layers of stone. The lowest layer consisted of three or four courses of flat stones; the second layer was composed of rubble masonry; the third of a finer layer of concrete on which was laid a pavement of large polygonal blocks of hard stone - jointed very carefully together. After construction, the total thickness of this road was about four feet. Many miles of roads similar in construction to the one described were constructed by

the Romans. These old Roman roads wore remarkably well, and at the present day, modern pavements are being laid on these old roads using them as a foundation.

The earliest forms of roads in the United States were simply strips of cleared land, and from these so called roads, developed the modern form of compacted and crowned earth roads with side ditches. Then there developed the improved hard surfaced roads, the earliest forms of which were those constructed of gravel and broken stone.

Up to the time of the introduction of the automobile, there were two forms of road construction which were considered as forming good roads. These were roads constructed of gravel, and those of broken stone. In the construction of such roads, the stone is laid on a well drained and compacted earth bed, and rolled. The interstices between the stone are then filled with a fine material such as clay, sand, limestone or traprock screenings, and this binder acts mechanically to keep out the water and thereby keeps the subgrade dry, and also to support the separate stones. The binder also acts physically and possibly chemically to bind the stone into a single solid mass. These stone roads were developed to withstand the wear of iron-shod horses' hoofs and iron-tired vehicles and they successfully met the demands made upon them by suburban and rural traffic until the advent of the automobile.

A good stone road is so constructed, and the rock from which it is made is so suited to the volume and character of traffic which passes over it, that the amount of dust worn off the surface stones is just sufficient to replace the dust removed by wind and rain. The dust remaining should just be sufficient to bind the surface stones thoroughly together, and so form a smooth and

impervious shell. A road of this kind wore uniformly under the traffic for which it was designed, and when properly maintained, presented a smooth, even surface.

CHAPTER 1.

Automobile Traffic.

Since the introduction of the automobile the traffic on our roads has been of such a changed character that a careful study of this new traffic is necessary before we can design good roads.

Motor cars were first seen on our city streets in 1899, but they were merely considered as the rich man's toy. From this date up to the present day, they have been greatly developed; and in 1906 we have a record of there being 150,000 automobiles in the United States. The output of automobiles, and the total number of cars in use in the United States from 1908 up to the present year is shown in tabular form.

YEAR	OUTPUT	TOTAL IN USE.
1908	55,000	150,000
1909	80,000	250,000
1910	200,000	300,000
1911	300,000	450,000
1912	400,000	1,000,000

The figures given in this table were gathered from different sources. For this reason they do not check up very well, but they are accurate enough for their intended purpose.

From this table it can be readily seen that the number of cars in the United States has assumed gigantic proportions, and therefore, the nature of the traffic on our roads has been greatly changed.

The growth and magnitude of the automobile industry may be shown by the fact that the capital invested in this branch of our

manufactories increased from $28,084,000 in 1904 to $173,800,000 in 1909 - an increase of 652% during the five year period.

In order that automobiles are to be of value, good roads are required for their use. The remarkable expansion in the manufacture and use of the automobile should make it a powerful factor in promoting the movement for better highways and highways which will withstand the wear of motor traffic.

It was quite generally believed by engineers before the introduction of the motor car that at least 80% of the wear on our roads was due to the action of iron shod horses' hoofs; consequently, the advent of the automobile was welcomed by engineers in the belief that this new type of vehicle having soft pneumatic tires would have a beneficial effect, if any at all, on road surfaces. As the number and speed of motor vehicles increased, however, it was soon found that the cost of road maintenance also increased, and at the present day, old methods of constructing and maintaining our highways are quite inadequate.

The first effect to be observed from fast motor traffic on stone and gravel roads is an excessive amount of dust raised from the road surface. This dust is not only a waste of material of which the road is composed, but it is in itself a nuisance as the wind and the air currents caused by the automobile itself carries the dust over adjacent property. The value of real estate and the comfort of nearby residents have been seriously effected by this nuisance. The soft pneumatic tires fail to produce any new dust from the rock of which the road is composed, with the result that the road surface is soon stripped of its binding material, exposing the upper or wearing course of stone. These stones, robbed of their binding material, are soon loosened

allowing water to make its way to the foundation, and causing the road to ravel and disintegrate. hese are the conditions that we find today, and which have to be met. The problem is such a serious one that engineers have given much study as to the action of the automobile on road surfaces, and many ingenious theories have been advanced. Among the many causes which were thought to contribute to the injury of the road surface was the slipping of the tires, skidding, shape of the car body, suction of the pneumatic tires, and shear caused by the driving wheels. These different causes will now be discussed and their relative values determined.

It has been demonstrated by connecting both the front and the rear wheels of an automobile to separate speedometers that there is a considerable amount of slipping of the driving wheels on the road surface, and on account of the irregularities on the average road surface, this is what should be expected. This slip due to the decrease in the bearing surface of the tire, undoubtedly increases the amount of dust thrown into the air. However, where the road surface is smooth, with but few irregularities, the slipping is greatly reduced, and the importance of this factor is greatly decreased.

The effect of skidding is only observable on roads that are subjected to fast motor traffic and on curves. On highly crowned roads the effect is to tear down the side slopes of the road, but this action is not serious. The effect on curves is to shift the crown of the road radially towards the outside gutter.

Experiments have been made which show that very little dust is actually raised from the road surface by air currents caused by the body of an automobile. Air currents are set up in the rear of

a car body, and they are dependent upon the shape of the body. Dust raised by the wheels from the road surface ~~by the wheels~~ may be greatly accelerated by these air currents, and carried completely off the road. It may be said, then, that air currents caused by the shape of a car body, do not directly effect the road surface; but once the wheels have raised the dust from the road it may be carried over a larger area due to this cause.

It has been claimed by some writers that a slight vacuum was created in the rear of each pneumatic tire, which was sufficient to lift the finer particles of the road surface in the air. Too much importance has been given to this phenomenon; and if it exists at all, its effect is probably so slight that it may be considered a negligible quantity.

In order to propel a motor vehicle the tires must exert sufficient tractive force to overcome the inertia and frictional resistance of the car. This must cause a shear on the road surface, which varies directly as the weight and speed of the vehicle. As a broken stone road surface has very little power to resist a shearing stress, the fine surface material of which it is composed is lifted from the road, and thrown into the air. Then the air currents caused by the body of the car and the wind help to remove the binding material entirely from the road.

A series of experiments were recently conducted under the direstion of L.W. Page, Director, U.S. Office of Public Roads. He used motor cars of various shapes and sizes - from the four thousand pound limousine to the small runabout. These cars were run at various rates of speed over a section of average broken stone road, and their effect on the road surface noted. The most interesting result was obtained with a sixty horse power car stripped

for racing, and weighing with driver and mechanician 2,800 pounds. The wheels of this car were thirty-six inches in diameter, with four inch front tires and four and one half inch rear tires. The car was driven over a section of broken stone road at five, ten, fifteen, and up to sixty miles an hour. The road used was a section of a government road which had been resurfaced two years previous to the test, and was in good condition. Photographers were stationed at a point designated for the proper speeds, and photographs were taken. Four of these photographs are shown as Figures 1,2,3, and 4 on pages 11 and 12. The action of the wheels are clearly shown by these photographs. The first picture shows the car traveling at ten miles per hour; the second at twenty; the third at forty; and the fourth at sixty miles per hour. Up to fifteen miles per hour little or no effect was produced on the road, and even at twenty miles an hour the observers concluded that no serious damage was done. From twenty miles an hour on, however, the effect was decidedly noticeable with each increase on speed.

The chief points which these photographs bring out is the different effect on the road, produced by the front and rear wheels. A very small amount of dust is raised from the road surface by the front wheels, and the amount does not vary with the speed of the car. The quantity of dust raised by the rear wheels varies directly as the speed of the car, and assumes large proportions when a speed of over twenty miles per hour is reached. If it were true that a vacuum was formed at the rear of each tire and sucked the dust from the road, the amount of dust raised by each wheel would be the same. This is not the case as the phographs prove that the <u>driving wheels alone</u> cause the damage, and

their action is due to <u>shear</u> and not <u>suction</u>.

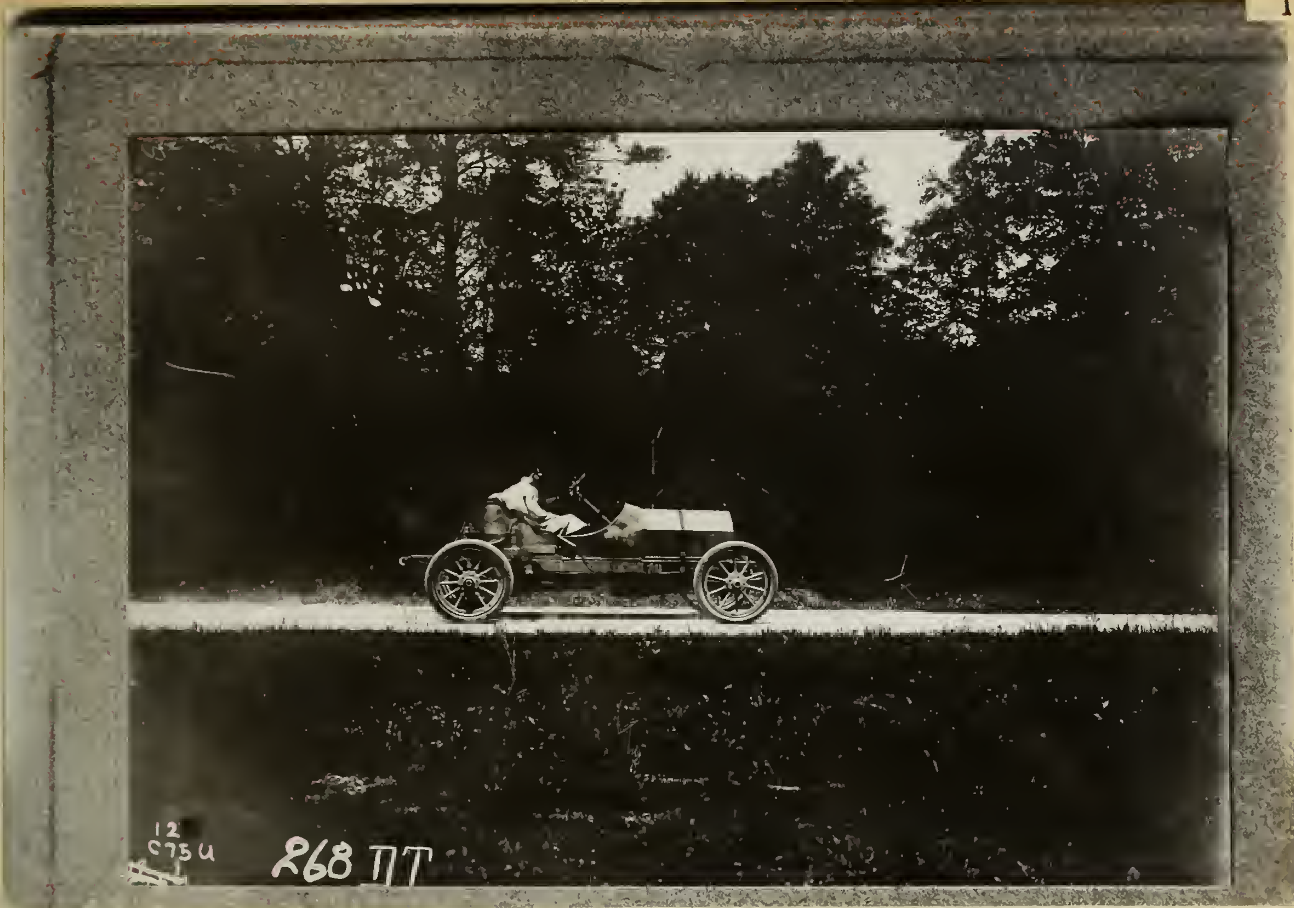


Fig. 1 10 miles an hour

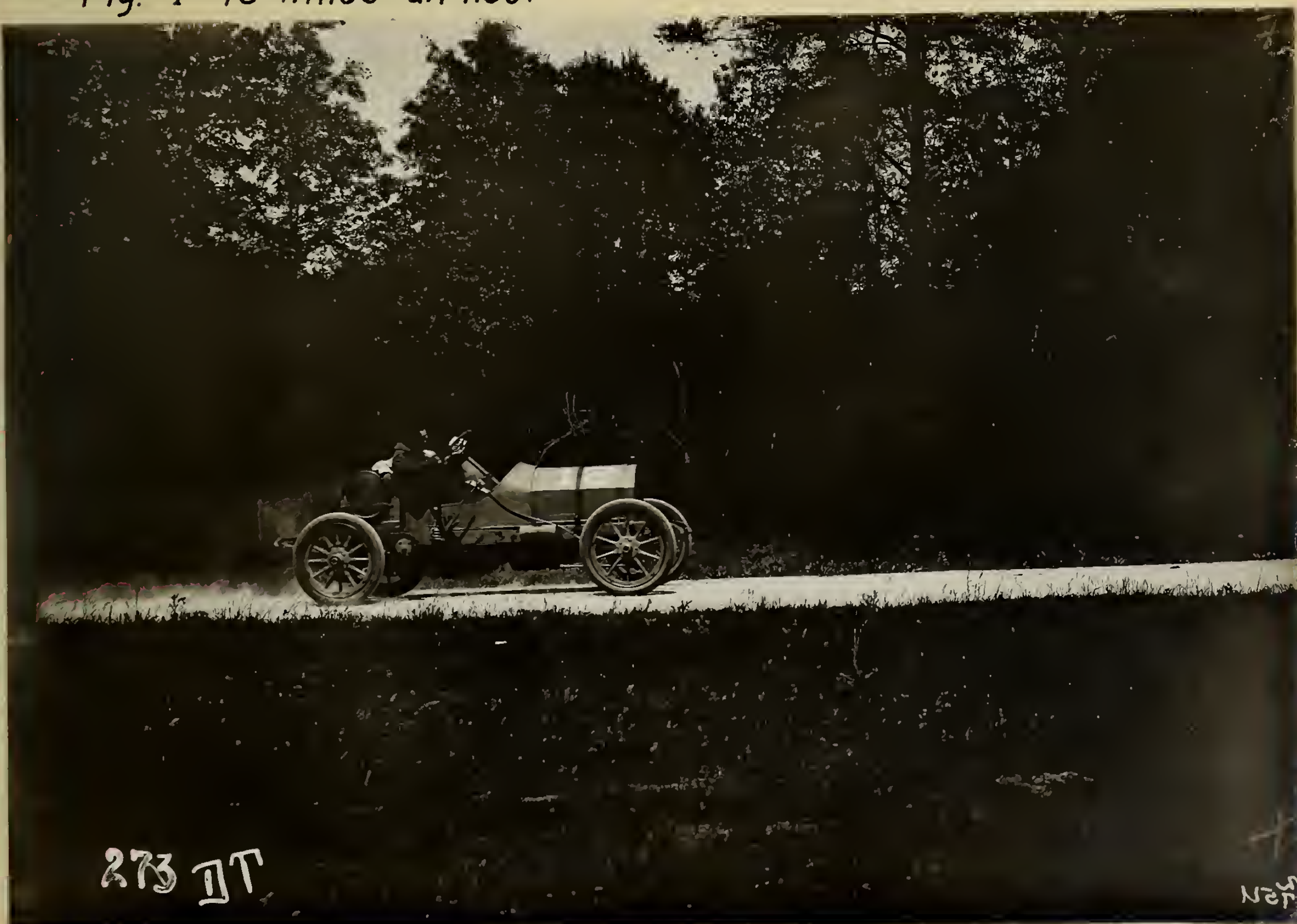


Fig. 2 20 miles an hour

Fig. 3 40 miles an hour

Fig. 4 60 miles an hour

CHAPTER 2.

Why Roads Should be Built to Resist Motor Traffic.

The application of mechanical arts to our daily convenience and comfort necessarily introduces new problems. So the motor vehicle has changed the roblem of good roads. The motor car when first introduced brought about severe criticism for its destructive action on our public highways. Now, however, it is admitted that the fault lies in our highway construction, and it is due to the motor car that the construction must be improved.. The advent of the motor car rendered most urgent the study of road preservation and improvement, and has led to the building of many miles of better highways and to the improvement of road conditions, which would otherwise not have been attained for many years to come.

The growth and magnitude of the automobile industry has been shown in previous figures to be a powerful factor in the development of our country. These figures indicate the possibilities which the motor car present, but these possibilities can not be realized without good roads.

The advantages of good roads for automobiles and their relation to our economic and social life are too numerous for this paper, but a few of the most important relations and what they really indicate will be taken up. We find that the motor car has become an important means of freight transportation. It is stated that today the public highways of France carry one and one third times more freight than the railroads of that country. Much of this freight is transported by motor trucks which have become an

efficient vehicle of commercial transportation. In England and Wales in 1908, there were 8,500 traction engines engaged in hauling over the rural roads. The farmers of our Middle West have adopted motor vehicles for their hauling as well as adopting the motor-traction and plowing machines for performing all the work of the season. Mr. Blackwell, an eminent English engineer, made the following statement in regard to this point:

"It may be taken now as a fact, whether the majority of the public like it or not, that haulage by traction engine is cheaper and more reliable than horse ~~horse~~ traffic for all heavy work, provided the roads are fit to carry it; the use of the traction engine is therefore bound to increase, and all highway authorities must make up their minds that the strength of the roads must be proportionately augmented to meet the requirements. A proof of this may be found in the growing difficulty experienced by highway authorities to prove a claim against traction-engine owners for extraordinary traffic".

Much has been said ~~at the present time~~ of the congestion of population in our large cities, and the abandonment of the farming lands. This has been going on for a number of years, as shown by the fact that in 1880 our city population (United States), was only 29.3% of the total population; while in 1890 it was 35.8%; in 1900, 40%; and in 1910, about 47 percent. The most hopeful solution ~~of the present time~~ for reversing this condition is the improvement of our roads, so as to make automobile travel possible. In this manner the automobile will make the country accessible to the city dweller, and the city available to the farmer. A proof of this is shown by the fact that at the present time, where road conditions permit, a large part of our city pop-

ulation live at a considerable distance from their city, and use the automobile as a means of travel between their place of business and home.

With the automobile and good roads, the area available for intensive agriculture is doubled. A case in England may be cited where each little truck farm in the neighborhood of London has its car, which is filled during the night with products for market. Early the next morning a powerful motor hooks onto the individual cars from each farm, and delivers the products at the market, returning with such supplies as the farmers may need from the town. Much of our farming land is rendered useless from the fact that the produce can not be carried to market at a low enough cost to carry on farming at a paying basis. With good roads and the area available for intensive agriculture doubled, we find one of the most reasonable solutions of the "High Cost of Living" question.

From these few examples the great possibilities which the motor car and good roads possess can readily be seen. Co-operation in the building of suitable roads is the one important need at the present day. A large per cent of automobiles are now owned by farmers. It is estimated that in the state of Iowa at least half of the automobiles are owned by farmers, and in the United States at large, one sixth of all the automobiles are owned by farmers. It is our country highways which need improving to fit them for automobile traffic, and with this large rank of helpers the task should be greatly simplified.

Good Roads.

In dealing with the road question, the all important fact

~~be dealt with~~ is the cost of constructing good roads. For this reason it would not be profitable to improve all of our country highways. Just what roads to improve is a question which is best decided by taking a traffic census of different highways, and comparing the data thus obtained. Investigations of this nature carried on by the Office of Public Roads, in San Joaquin County, California, revealed the startling fact that 20 per cent of the roads of that county carried 90 per cent of all the traffic. In other words, a road system comprising but one fifth of the roads of that county would serve the needs of nine tenths of the traffic of the entire county.

A very important phase of the good roads question is the consideration of the cost of maintenance after our roads have been built. All forms of roads must be properly maintained if they are expected to last any length of time and develop their greatest efficiency. It is only too true that in the past this important consideration has in many cases been sadly neglected, and many people believed that once a good road was built, it would last practically forever without any expense for maintenance. Many miles of good roads have been built in this country without any provisions being made for maintenance, with the result that at the end of two or three years the roads have become practically worthless and the money invested has been wasted. As the motor car comes into more general use, the question becomes of even greater importance, and it is thus seen that hereafter it will be of equally great importance to provide adequate maintenance for our good roads, as it is to construct them.

CHAPTER 3.

EARTH ROADS.

Earth roads are roads whose surface consists of native soil, such as loam, clay, or sand. They are constructed by forming the surface into a proper crown with side ditches for surface drainage. Tile may be laid to take care of the under drainage of the road bed. Drainage is the most important item to be considered in the construction of earth roads, since an earth road is only passable when it is maintained in a dry condition. If water be allowed to remain on an earth road, it soon mixes with the earth and forms mud which is too soft a material to support any kind of traffic.

The fact that an earth road is the cheapest form of road construction, renders it necessary that this form of road be considered and its economic value under traffic studied, so as to determine under what conditions it is justifiable to replace it with a better type of construction. And further since there are many miles of such roads which evidently can not be permanently improved, the earth road must also be studied from a structural standpoint in order that it may be so constructed as to be reasonably satisfactory. Also the fact that the original earth road is the best preparation for any improved road construction, should not be lost sight of. In some of our states where hard road construction is contemplated, earth roads are first improved, or built, and thus a good foundation for some hard surfacing is prepared.

There is a traffic intensity for each kind of soil beyond

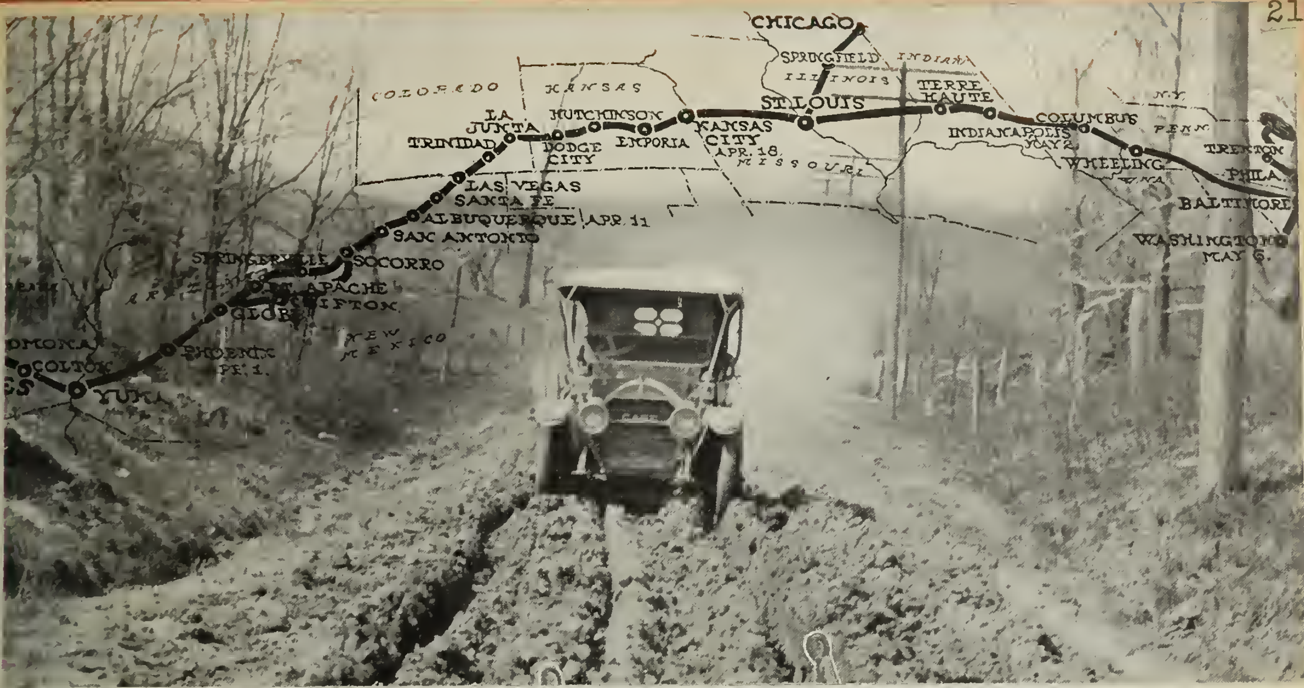
which it becomes uneconomical even to attempt to maintain an earth road, and there are certain soils, such as light sands and absorbent adhesive clays, which can be but little improved by maintenance. On the other hand there are vast regions where the country is not built up sufficiently to warrant the construction of more expensive roads, and our common earth roads may be so built and maintained as to answer the requirements for many years to come. Earth roads must be studied under two conditions - when they are in a dry condition, and in a wet condition. The ~~nature of traffic,~~ ~~or to~~ weight that a dry earth road can support depends upon the bearing power of the soil, and it is usually found to be the case that such a road is unfit for heavy traffic. In a dry condition, such a road stands medium horse-drawn traffic well, and it stands automobile traffic better than a broken stone road does. An earth surface has very little shearing strength, and therefore much dust may be raised by automobile traffic, but after each rainfall most of this dust is again compacted into the road. An entirely different condition is found when considering a wet earth road. In this case, the surface has very little supporting power, and can not withstand either horse drawn traffic, ~~loads~~, or automobile loads. The surface is soon cut into deep ruts, and there results an elongated mud hole in place of a road.

We have become so familiar with earth roads in their impassable and neglected condition that we can hardly form any conception of their being anything else. Yet it has been demonstrated that where the natural soil is of the proper consistency, and adequate means of drainage have been provided, it is ossible with systematic ~~form of~~ maintenance to transform the road into a fairly good highway, at least for a part of the year.

The main objection to earth roads are that they never make a good highway during all the seasons of the year. If earth roads could be constructed so that their surface should be practically impervious and the sub-grade kept dry, then such a condition would produce a good road. Soil however absorbs water easily, so these conditions are impossible. Earth roads which are excellent during the dry months lose all semblance of a road during the months of rainfall, freezing, and thawing, and may become quite impassable at such times. These conditions affect automobile traffic more so than horse-drawn traffic. When an earth road contains much clay, water renders the surface very sticky and slippery, so the rear wheels of an automobile can receive no tractive resistance from such a surface. If the surface of an earth road freezes while in an uneven, rough, and rutty state, it is almost impossible for a motor car to travel over it, to say nothing of the discomfort suffered by the occupants of the car. It can be said of earth roads that they meet very few of the conditions for which they were intended, and therefore their use is only excusable on the grounds of low first cost.

The first cost of earth roads varies greatly in different parts of the country. Their cost being increased where deep cuts and fills are necessary, or where many stream crossings must be built. From data collected from different parts of the United States the cost of earth roads per mile including drainage and shaping, varied from $97.00 to $1800.00. The average cost per mile being $450.00. Considering the average width of road as 18 feet, this would make the average cost per square yard to be 4.26 ¢. There is no limit to the life of an earth road, and after being built the only expense is for maintenance. Where a split log drag

is used for maintaining an earth road surface, the average cost of dragging per mile per annum varies from $2.00 to $5.00 depending upon the cost of labor and the number of times the road is dragged during the year.



Bad Roads on the Trans-continental Route.

Illinois.

A. Harrisburg Township, Saline County. Independence road before improvement.

Illinois.

A. This condition of an earth road was found during September. Shows utter lack of any intelligent care. A few loads of earth to raise the road here would prevent any such mud hole in summer time, at least.

Mixing Sand and Clay in Florida.

A well built earth road. Note broad, shallow, sodded gutters. Center maintained with drag.

CHAPTER 4.

GRAVEL ROADS.

Gravel roads and broken stone roads are similar in many respects, but when broken stone is used the foundation is usually constructed more scientifically, and the road then assumes the name of a macadam or telford road.

There are different methods used in the construction of gravel roads, but the principal is the same. Gravel is spread on a well drained earth road, to a depth of from four to eight inches, and leveled off so that it assumes the general cross section of the road. The surface is then either rolled with a steam roller, or left to be compacted by traffic. In this manner the surface stones are forced into contact, and become more or less firmly cemented together, forming an impervious road surface.

An important fact that has often been overlooked by road builders is the fact that all gravel is not suitable for highway construction. To be suitable for this purpose, the stone must be hard and tough, so as to resist impact of wheels and horses hoofs. It should contain different sized material, each in the proper proportion, so as to make a homogeneous mixture with few voids. There should be contained in the gravel a fine binding material which will cement the whole into a solid mass. If the gravel is too sandy, it does not pack well, nor does it contain sufficient binding material to hold it together through a season of drought. Another common deficiency of gravel for road building is that it may contain too great a proportion of coarse material. ~~which is not uniformly distributed~~. The result is the surface of the road wears unevenly, becomes rough and holes form in the surface.

When gravel does not contain the right proportions of coarse and fine material, it should first be screened, and then remixed so as to remedy the defect.

It requires as much, if not more skill, to build a good gravel road, as it does to build a good macadam road. First, careful study is required in the selection of a suitable gravel. Then to spread the gravel so that the road will be smooth and comfortable to ride over, requires a degree of skill few road builders possess.

The theory of the gravel road is essentially the same as for that of a broken stone road. That is, under wagon traffic, the amount of binding material worn from the road surface is just sufficient to replace the dust carried away from the road by wind and rain. By this theory there is always sufficient binding material on the road to bind the pebbles together, and so form an impenetrable shell. Under wagon traffic a well constructed gravel road gives almost as good results as a broken stone road, and before the appearance of the motor car many miles of good gravel highways were constructed. With the changed nature of traffic due to the motor car, such roads were found to be entirely unsuited to these new conditions. The reasons for this are taken up in detail in the first part of this paper.

A gravel road has one advantage over an earth road, in that the hard impenetrable surface of the former is almost equally good throughout the entire year. On the other hand, its main disadvantage is the high cost of maintenance. A gravel road must be carefully watched, and all ruts and depressions should be filled as soon as they are formed. If this is not done, water will collect in such holes and cause the softening of the gravel bed. The impenetrable shell of the road will be destroyed, allowing water

to reach the sub-soil, and so soften the foundation.

Good gravel abounds in so many of our states, and may be obtained at such a low cost that even at the present day many miles of our earth roads are being improved by gravel construction. It may be here stated that under the following conditions of traffic, gravel roads may be economically constructed.

1. Roads subjected to only moderate automobile traffic and light horse-drawn traffic, where local stone is available.

2. Parkways and pleasure drives where a continuous system of maintenance is possible.

3. As a pavement low in first cost for suburban streets where traffic is light.

The first cost of constructing gravel roads varies for different states, from $600.00 to $3900.00 per mile. The average cost per square yard may be taken as $.25. These figures do not include the cost of constructing the original earth road. A carefully constructed gravel road which has been rolled with a steam roller, would probably cost $.50 per square yard. Using this figure the annual cost of this pavement has been calculated.

Assumed period of life of pavement	10 yr.
Assumed life of bonds at 4%	10 yr.
Assumed first cost of pavement	$.50 per sq. yd.
Assumed cost of ordinary repairs after 1st yr.	$.05 per Sq.Yd.
Interest on first bond issue .04 by .50 by 10 -----	$.2000
Sinking fund at 3½% interest to retire first bond issue .08524 by .50 by 10 ---------	.4260
Cost of ordinary repairs .05 times 9 ---------	.4500
Cost for 10 years per square yard -----------	$1.076
Annual cost per square yard ------------	$.1076.

B. Uusual Method of Spreading Gravel which is Left for the Traffic to Smooth and Compact. Road Near Elburn, Kane County.

A. Woodside Township, Sangamon County. Springfield experimental road built in 1906. View taken March 3, 1908. In foreground is seen ravelled gravel portion of road, immediately beyond is limestone. The junction of the stone and gravel is sharply defined.

Roads in Illinois.

WEST SIDE TRUNK LINE.

Under construction. North of Keene. Gravel. Creases are due to grooved roller used in compacting the gravel.

Gravel Road, Maynard.

CHAPTER 5.

MACADAM AND TELFORD ROADS.

A broken stone road either of the telford or macadam type is constructed by placing fragments of stone on a well drained earth road bed, and compacting them into a solid mass - the stone dust acting as a cement to bind the stones firmly together.

The construction of a good broken stone road requires a material that is hard, tough, able to resist weathering, and whose dust has great cementing power. Stone which is classified under the common name of trap has been found to answer the requirements better than any other. The selection of stone for road building purposes is ~~also~~ governed by the nature of the traffic which is to come upon the road. Where traffic is to be exceptionally light, a hard stone may not furnish enough dust to replace that blown away by the wind and washed away by water, in which case a softer stone or one possessing greater cementing power may be preferable.

There are in general two methods of constructing broken stone roads. The macadam type of road is constructed by placing two or more layers of crushed stone upon the road bed of earth. The telford type consists of a foundation of rough stone blocks set upon the road bed, covered with one or more layers of crushed stone. Very little distinction is now made between these two types of construction, the paved foundation being used only where the earth foundation is soft, or where traffic is heavy enough to warrant it.

Formerly all broken stone roads were constructed by placing

the larger stones in the lower course and ~~ranging the different sizes~~, using the smaller stones for the surface. Recently, however, it has been demonstrated that if the stones are laid in reverse order, that is, the smaller stones in the foundation, and the larger ones at the surface, the road will wear better. The theory of this construction is that the pressure bearing upon the foundation stones in a road is not nearly as great as the pressure which comes upon the surface stones. A larger stone is better able to resist crushing than a smaller stone, so these stones are placed at the surface.

Broken stone roads were constructed to meet the conditions of horse-drawn traffic, and previous to the introduction of the motor car, they were one of our best types of roads. Since the advent of the car conditions of traffic have been entirely changed, and macadam roads have proved to be quite unsatisfactory. The effect of automobiles on broken stone roads has been studied in detail in the first part of this paper, and the adequacy of this type of pavement for motor traffic was disproved.

A carefully constructed broken stone road possesses better wearing qualities than does a gravel road. For streets subjected to light ~~local~~ traffic, such as suburban streets, parkways, and pleasure drives, the use of macadam may give satisfactory results. If well constructed and properly maintained, it will have a life of about ten years, and the cost of repairs will not be excessive. Proper maintenance of a stone road is very essential. A rut or depression formed in the road surface must be immediately repaired, for if it is not done, one stone after another will work loose, and the road will ravel. Also these depressions will hold water in case of wet weather, soften the road, and penetrate to the founda-

tion. The great need for continual maintenance on roads of the macadam type is one of their greatest disadvantages. The main advantage advocated for their construction is the low first cost. At the present day however macadam roads are found to be economical in but few cases, and people are realizing the fact that low first cost may prove very expensive in the long run. Many miles of these roads have been built where much automobile traffic prevailed, with the result that after one or two years of use, the roads failed completely, and more permanent roads will have to take their place.

The annual cost of this pavement has been estimated for purposes of comparison upon the assumption that it will be paid for by the issue of bonds running for a term of ten years. Maintenance cost is estimated as $.06 per square yard. This is true for light traffic only - under increased traffic the maintenance charge increases rapidly.

Annual Cost of Macadam.

Assumed period	10 years.	
Assumed life of pavement	10 years.	
Assumed life of bonds	10 years.	
Assumed first cost of pavement	$1.00 per Sq. Yd.	
Interest on first bond issue (.04 by 1. by 10)is		$.4000
Sinking fund at 3½% of interest on first bond issue (.08524 by 1.00 by 10)is ---------		.8524
Cost of ordinary repairs (.06 by 9) is		.5400
Total cost including maintenance for 10 years per square yard is		$1.7924
Total cost including maintenance for 1 year per square yard is		$.179.

An Example of what Happens to a Plain Macadam Road Under Automobile Traffic.

Automobile Raising Dust Cloud.

ONONDAGA COUNTY.— Macadam road built by town superintendent. Considerable grading work was done, grade being reduced from 15 per cent. to 11 per cent. Standard macadam laid in two courses, width 16 feet. Penitentiary prisoners were used, thus reducing cost about one-half. Length of improvement, 1,000 feet, cost $500.

Ohio.

Harrisburg Township, Saline County. Independence road after improvement. Water bound limestone macadam, built 1909. Photographed, July, 1910.

Illinois.

CHAPTER 6.

BLOCK PAVEMENTS: (STONE, BRICK, WOOD.)

Under this heading will be discussed types of road surfaces composed of blocks of various materials, laid in some regular pattern.

Stone Block Pavements: The earliest form of these pavements were constructed by laying cobble stones upon an earth foundation. The cobble stones were smooth and rounded, and could not be laid close together, therefore a smooth surface could not be obtained with such stones. Next roads were constructed with blocks of roughly dressed stones, and these were gradually improved, until finally they developed into the oblong granite block of the present day.

In order to obtain the greatest durability from a block pavement, the weight of the traffic should be applied directly on top of the blocks. If the blocks are not laid closely together, the wheels of vehicles will slide into the cracks, abraiding the blocks and causing them to wear unevenly. The blocks must also be laid upon a firm foundation, for if this is not done the surface of the pavement will become uneven, due to the sinking of some of the blocks. This will cause wheel loads to come upon the edges and corners of the blocks, resulting in uneven wear due to shear and abrasion. Formerly granite block pavements were laid without the use of cement, either in the foundation or for the purpose of grouting the joints. The blocks were placed on a sand cushion about two inches thick, which in turn was spread upon the natural earth. After placing the blocks, they were rammed, and

the joints filled with sand. Such a block pavement did not prove to be satisfactory. The pavement settled unevenly, the individual blocks being pounded down below the general surface of the pavement. The blocks were not laid close together, and as the sand filler offered little support to the edges of the blocks, they were sheared off by the impact of the horses shoes and by the tires of vehicles. This wear caused the blocks to become rounded or curved at the top, forming a very noisy and uneven pavement. Such a surface was also very unsanitary, the wide joints forming receptacles for foul dirt which accumulated on the surface of the pavement.

The modern type of granite block pavement is constructed with carefully dressed blocks which may be laid close together. These blocks are laid upon a two-inch sand cushion, placed on a concrete foundation from five to ten inches thick, depending upon the weight of traffic the pavement is to support. The joints are then grouted with portland-cement mortar. An asphalt filler should never be used for this purpose, as it does not offer sufficient support to the edges of the blocks, nor will it remain permanently as a binder. The ultimate result is that it dries up, losing its binding qualities, and it will then be chipped off and washed out from between the blocks, and the condition of the pavement will be as bad as when sand is used for a filler.

Granite block pavements are not effected by automobile traffic. It will withstand the heaviest traffic better than any other pavement, but its first cost is probably too great to warrant its being used except on streets subjected to voluminous traffic of a heavy nature, as comes upon streets in the manufacing and railroad districts.

In estimating the annual cost of a granite block pavement, it has been assumed that traffic conditions are such as would ordinarily be met with on a city street subjected to the heaviest traffic. Under these conditions, and if properly laid, its life as a whole may easily be taken as forty years. It is assumed that at the end of this period, the cost of repairs will have become so great that it will be better economy to tear up the entire pavement, and construct a new one.

The first cost of a granite block pavement with a six inch concrete base is estimated at $3.50 per square yard. Bonds issued for a period of 10 years. The cost of ordinary repairs may be taken as $.02 per square yard per year for the last ten years of the life of the pavement.

Assumed period	40 years.	
Assumed life of blocks	40 years.	
Assumed life of base	40 years.	
Interest on first bond issue (.04 by 3.50 by 10) is		$1.400
Sinking fund for first bond issue (.08524 by 3.50 by 10) is		2.980
Cost of ordinary repairs (10 by.02) is		.200
Total cost per Sq.Yd. for 40 years is		$4.580
Total cost per Sq. Yd. for one year is		.1145.

BROADWAY, NEW YORK CITY — AT LEONARD STREET. GRANITE-BLOCK PAVED, INCLUDING BETWEEN STREET-RAILWAY TRACKS

BOSTON, MASSACHUSETTS — PURCHASE STREET. GRANITE-BLOCK — PAVED 1904. PHOTOGRAPHED 1910

NEW YORK CITY—Two Heavy-Traffic Streets along the Water-Front where all Freight is Carried to Railroad and Steamship Docks. A—South Street. B—West Street. Granite-Block—Paved 1908.

Brick Pavements: A brick pavement consists of brick set on edge on a suitable foundation. Brick pavements were constructed in Holland as far back as 1800, but they were first used in the United States in 1870 at Charleston, West Virginia. Originally the brick was simply laid upon the earth road bed; but as in the case of the granite block pavements, such a foundation did not prove to be firm enough, and the pavement settled unequally, and soon attained a very unsatisfactory sondition. Brick pavements are now constructed in the same manner as are granite block pavements, and most of the principles of the latter may be applied to brick pavements.

Brick being a manufactured product, may be obtained in uniform sizes, with smooth edges and surfaces. For this reason they may be laid close together, and will form a smooth paving surface. The joints should be filled with portland cement grout. It has been the custom to use a bituminous filler for brick pavements in order to produce a less noisy pavement. This practice should be discontinued, since as previously stated a soft filler does not support the edges of the brick and prevent them from shearing off, and also because such a filler is not a permanent binder. Brick forms a pavement which is smooth and durable. It is easily cleaned and not excessively noisy. It is an ideal pavement for automobile traffic, as no appreciable wear is caused by the soft pneumatic tires of motor vehicles, and it gives good grip, wet or dry. The only objection to this type of pavement under horse-drawn traffic is the noise caused by iron-shod horses' hoofs and iron-tired wheels. On boulevards, parkways, and many of our highways, horse-drawn traffic is very light, and comprises but a small per cent of the total traffic. This will lead us to the conclusion that a brick

pavement is readily adapted for the roads above mentioned. A brick pavement wears exceptionally well under horse-drawn traffic of any nature, and if properly laid may be used on any city street.

In computing the annual cost of this pavement, it is assumed that it is to be laid on a city street subjected to fairly heavy traffic of all kinds.

The estimated cost of brick pavement is $2.25 per square yard, including a six inch concrete foundation. If properly laid, its life as a whole may be taken as 40 years, at the end of which time the cost of repairs will have become so great that it will be better economy to tear up the entire pavement and construct a new one. The cost of ordinary repairs may be taken as $.02 per square yard per year for the last ten years of the life of the pavement.

Assumed period	40 years.
Assumed life of blocks	40 years.
Assumed life of base	40 years.
Interest on first bond issue (10 by 2.25 by .04) is	$0.9000
Sinking fund first bond issue (.08524 by 10 by 2.25) is	1.9200
Cost of ordinary repairs (.02 by 10) is	0.2000
Total cost per Sq. Yd. for 40 years is	$3.0200
Total cost per Sq. Yd. for one year is	$0.0755.

COLUMBUS, OHIO—EAST RICH STREET. BRICK-PAVED 1892

Brick Road, Near Monmouth, Warren County, Ill.

DOWNERS GROVE, ILLINOIS—PRAIRIE AVENUE. BRICK-PAVED 1909

ST. CLAIRSVILLE, OHIO—Main Street. Brick-Paved 1907

WILLIAMSPORT, PENNSYLVANIA—West Fourth Street. Brick-Paved 1893. Photographed 1909

CHICAGO, ILLINOIS—GROVELAND AVENUE. BRICK-PAVED 1896—14 YEARS AGO. PHOTOGRAPHED 1909

BUTLER, PENNSYLVANIA—MAIN STREET. BRICK-PAVED 1888. PHOTOGRAPHED 1909

Wood Block Pavements: Wood pavements were used as far back as 1831 and since then they have been steadily improved. The earliest wood pavements consisted of cylindrical blocks of any convenient wood laid upon a sand cushion which was in turn spread over an earth foundation. In 1860 the Nicolson patent was granted which provided that blocks of this form should be laid on planks. Pavements of this kind proved to be a complete failure. The blocks could not be laid close together, leaving large irregular spaces between, so that loads were not applied directly on top of the blocks. The edges were crushed and worn away, and in a short time a very rough and uneven street surface was formed. The joint served to hold water and dirt;and the wood used was not treated in any way, and soon the foundation planks and blocks decayed, with the result that the pavement wore unevenly, depression were formed, and the decayed wood held much moisture and dirt, and became very unsanitary.

The modern wood pavement pavement is constructed on a concrete foundation. This foundation is made from four to eight inches in thickness depending upon traffic conditions. On this foundation is placed a one and a half to two inch layer of sand or a half inch layer of mortar, and on this are laid the wood blocks. The blocks are rectangular and uniform in shape, usually being four inches deep, four inches wide, and from six to eight inches long. They are chemically treated with a wood preservative so as to prevent decay. The joints between the blocks are grouted with portland cement mortar or filled with some bituminous material. A bituminous filler will not produce as permanent a pavement as would portland cement grout, but it may be used with wood blocks, as the tendency of the blocks to shear off at the corners is not great. These modern wood blocks may be laid closely together, and

thus traffic will always be applied directly on top of them, causing the pavement to wear evenly. The blocks are laid with the grain of the wood vertical in order to produce greatest durability.

A modern wood pavement is practically ideal when dry. It is slippery however in moist or frosty weather, as are all of our modern smooth pavements. It is noisless and sanitary as there is little opportunity for the collection of dirt, and it may be easily cleaned.

Wood pavements are recommended for street traffic of any sort, near retail houses or office buildings where the elimination of noise is important. The cost of this pavement prohibits its being used for highways or less important city streets.

Under such conditions of traffic previously mentioned, a wood block pavement should have a life of at least fifteen years, at the end of which time the maintenance cost will have become so great as to necessitate a new block surface. The estimate first cost of this pavement is $3.75 per square yard.

Assumed period	40 years.
Assumed life of blocks	15 years.
Assumed life of base	40 years.
Guarantee period	5 years.

Life of bonds 10 years at 4 %.

Interest first bond issue (.04 by 10 by 3.75) is	$1.5000
Sinking fund to retire 1st bond issue (08524 by 3.75 by 10) is	3.1965
Interest on second bond issue (.04 by 2.75 by 10)is	1.1000
Sinking fund 2nd bond issue (.08524 by 2.75 by 10) is	2.3441
Interest third bond issue (04 by 2.75 by 2/3) is	0.7333

Sinking fund third bond issue (.08524 by 2.75 by 10 by 2/3) is	\$1.5627
Cost of ordinary repairs (05 by 15) is	.7500
Total cost for 40 years per Sq. Yd.	\$11.1866
Total cost for one year per Sq. Yd.	.2797.

CHICAGO, ILLINOIS—Monroe Street, Front of First National Bank Building
Creosote-Block—Paved 1907

Barrett's Coal Tar Paving Pitch Filler

MOBILE, ALABAMA—Creosoted-Block—Paved 1905

Barrett's Coal Tar Paving Pitch Filler

CHAPTER 7.

SHEET ASPHALT PAVEMENTS.

Sheet asphalt pavements were first constructed in this country in 1870. Since then many streets have been paved with this material, and in 1900 it was estimated that there were 38,000,000 square yards in the United States.

A sheet or monolithic asphalt pavement must have a firm foundation. This foundation is usually constructed of portland cement concrete, and is made from four to six inches thick. Upon the foundation is laid the binder course, which consists of a layer about one and one half inches thick of broken stone cemented together with asphaltic paving cement. The purpose of this binder course is to bind the surface wearing coat, and the foundation firmly together. The wearing coat is then spread upon the binder course to a depth of one and one half inches to two and one half inches, and is composed of asphaltic cement and sand mixed to the proper consistency.

The selection of a good grade of asphalt is a very important matter. It must be of such composition as to render the asphaltic cement neither too soft nor too brittle. If the asphalt does not contain the proper amount of bitumen, the road surface will be brittle, and will crack readily; while an excess of bitumen will cause the road surface to be soft and not able to resist pressure brought upon it by traffic. The asphalt should not contain salts which when dissolved by rain water leaves the pavement porous and subject to the disintegrating effect of acids and oxygen in

rain water.

A good grade of asphalt may be ruined before it is put on the street by burning or overheating. The effect of burning will cause the asphalt to lose its cementing power, and a pavement constructed of such material will soon disintegrate under the action of traffic.

All asphalts gradually lose their cementing power with age by volatilization, evaporation and oxidation. Asphalt on a street surface is exposed in a great extent to the action of the sun's heat, and to the wind and rain. For this reason an asphalt pavement will gradually dry up, and become brittle. Cracks will form especially during cold weather, into which water may penetrate, and thus aid in the disintegration of the pavement. The disintegrating effect of water depends upon its contained oxygen, and its deteriorating effect upon asphalt varies with the proportion of soluble salts present. Cracks in an asphalt pavement not only hold water and mud which rot the asphalt near the edges of the crack, but this water is also permitted to reach the interior and foundation of the pavement, where it also has a deteriorating effect.

In order that an asphalt pavement be as permanent as possible, prompt maintenance must be supplied at all times. This maintenance is necessarily expensive as practically the same plant and equipment is needed as in the original construction of the pavement.

At the present day, asphalt pavements are constructed to a limited extent, and are found to be economical in only a few cases for the following reasons. In their construction both the binder course and the wearing course must be heated to a temperature of

300 degrees F. before being laid upon the road. This increases the cost of construction, and an expensive plant and equipment are needed. This pavement requires maintenance and practically the same plant is needed for this work.

An asphalt pavement is smooth, noiseless, and sanitary. It is unsuited for extremely heavy traffic, as the wearing surface does not offer sufficient support for heavy loads. Asphalt is also unsuited for very light traffic because without the ironing action of traffic the surface becomes brittle and cracks will form. Automobile traffic has a beneficial effect on this kind of pavement.

Where traffic is moderate in weight and not sparse as in many residential sections and important suburban streets, and where the question of economy does not receive as great weight as does the advantages of an asphalt pavement, it may be advisable to lay this kind of pavement. It is understood that in such cases, adequate funds must be provided for maintenance.

The first cost of this pavement with concrete base is estimated at $2.80 per square yard, and the cost of renewal at the end of each period of ten years at $2.00 per square yard.

Assumed period	40 years.	
Assumed life of base	40 years.	
Assumed life of pavement	10 years.	
Assumed life of bonds 10 years at 4 %.		
Guaranty period of five years four times.		
Interest 1st bond issue (.04 by 2.80 by 10) is		$1.1200
Sinking fund 1st bond issue (.08524 by 2.80 by 10) is		2.3880
Interest 2nd, 3rd, and 4th bond issues (.04 by		

2.00 by 10 by 3) is	$2.4000
Sinking fund 2nd, 3rd, and 4th bond issues	
(.08524 by 2.00 by 10 by 3) is	5.6800
Cost of ordinary repairs (.15 by 20) is	3.0000
Total cost for forty years perSq. Yd. is	$14.5880
Total cost for 1 year per square yard is	.3640

ASPHALT PAVEMENT

SARCOLITHIC Mineral Rubber Pavement, City Park Ave.,
New Orleans, La.

CHAPTER 8.

BITUMINOUS BINDER PAVEMENTS.

Many remedies have been suggested and tried for overcoming the destructive effect of motor traffic. Experiments have been made with many so called "dust preventives" with the object of obtaining a powerful binder that would hold the dust to the road surface and also hold the stone in place. These experiments have been carried along two general lines, either to add some palliative to the surface of old roads, or to construct a new road with a binding material that would hold the stone in place.

Binding materials as now used on our roads may be divided into two classes - temporary and permanent binders. The temporary binders serve merely as dust palliatives, and require frequent renewal. The permanent binders enter into the structure of the road as a constituent element, and are effective for a longer period of time than are the temporary binders.

In the class of temporary binders may be included, water, salt solutions, light oils, and tars, and oil and tar emulsions. The permanent binders include petroleums containing an asphaltic base; the residues of such petroleums, heavy tars, pitch; and numerous oil, tar, and asphaltic preparations. In addition to these, a few special materials have been the subject of experiment, such as waste products from beet and cane sugar factories, and waste liquor obtained from the sulphite-process wood-pulp mills. Glue and bichromate of potash have also been used in combination with oil and tar emulsions to cause the residue upon the road

surface to harden after the volatile products have evaporated.

Water while usually the most abundant and cheapest material, is often, because of the frequency with which it must be applied, the most expensive to use. Its binding power is slight, being entirely due to capillarity. It does however tend to give cementing power to stone dust, and is often of value for this reason. The value of salt solutions commonly used, lies in the hydroscopic character of the dissolved salt which having considerable affinity for water keeps the road in a moist condition. The light oils and tars are dependent for their effect upon the retention by the road surface of a comparatively small amount of true binding base after the volatile products have evaporated. This base proves effective only so long as it retains its binding power, and must be renewed at frequent intervals.

The heavy oils and tars differ from the lighter products in that they contain a much greater per cent of asphaltum, which constitutes the binding base. The results obtained with such materials are therefore of a more lasting character.

A few earth roads in California, and gravel and macadam roads are the only ones whose surfaces it has been found economical to treat with a dust preventive. In the surface treatment of these roads one of the most important questions is the selection of proper binding materials. A large percentage of the failures of treated roads have been due to the application of inferior materials, those deficient in certain well known necessary characteristics. The usual method of applying these materials to the road surface is by sprinkling. Temporary binders can be applied cold, but the permanent binders, because of their much greater viscosity, must be heated until sufficiently fluid. Machines are now in gen-

eral use for this work, in which the binder is heated and applied to the road surface as a spray under high pressure. These so-called tar sprayers are not only economical in the use of material, but insure a more even distribution and deeper penetration of the road surface than is possible to obtain by hand spraying.

In the construction of dustless roads the main question is that of cost. If a material is applied to a road surface that will hold the dust to the road, automobile traffic can do but little damage. Such a road surface however will not withstand the action of horse-drawn traffic to a great extent. Heavy wheel loads and horses' hoofs cut through the surface coating, and cause disintegration. If however traffic is confined to light carriages, and the proportion of automobile traffic is large, little damage to the road will result. The passage of a large number of automobiles iron out the marks of hoofs and the grooves cut by steel-tired wheels, almost as rapidly as they are formed. The conclusion may be drawn that for the preservation of existing roads, where the money is not available for more suitable construction, surface treatment may be resorted to; but when the road is sufficiently worn out to require re-surfacing, or when a new road is to be constructed, it is far better policy to construct a more permanent form of road.

-Application of Oil to Macadam Surface.

-Fast-Moving Automobile on Oiled Road Raising no Dust.

MERRIMACK VALLEY TRUNK LINE BETWEEN CONCORD AND NASHUA.

Showing that a heavy surface oil treatment stands the automobile traffic better than horse-drawn traffic. Wheel tracks are in good condition. Path in center is cut up by calks on horseshoes.

NEW HAMPSHIRE

Macadam Road with Oil Surface, Lakeville.

NEW HAMPSHIRE

Bituminous Pavements: Bituminous pavements are constructed by incorporating strong bituminous binders into the road during construction. This binder should be selected from the class of permanent binders. The two methods of incorporating the binder into the road metal are by the penetration and by the mixing method. In either case, a suitable foundation is prepared which may consist of a four to six inch layer of concrete, or it may be prepared in exactly the same way as in macadam construction, using broken stone.

For the penetration method, a wearing course of broken stone is laid to a depth of about three inches upon the prepared foundation, and rolled till the stones interlock. The bitumen is then heated and sprayed by hand or machine over the surface. From one to one and a half gallons of the bitumen should be used per square yard of pavement. This penetrates the wearing course, filling all voids, and coating the stones, leaving some bitumen on the surface of the road. Clean stone chips are then spread over the surface to a depth of about one inch, and then the road is well rolled.

In the mixing method the aggregate of the wearing course, which consists of carefully graded stone, is heated to a temperature of about 250 degrees F. and then thoroughly mixed by machine with hot bitumen. This hot bituminous concrete is then spread upon the foundation to a depth of from two to four inches, and rolled. The surface is then covered with a thin coating of bituminous composition, and over this is spread a thin layer of fine hot crushed stone. The road is then well rolled. Bituminous pavements will produce better results when constructed by the mixing method, as the stones are assured sufficient binder to thoroughly cement them

together, and this binding material is distributed uniformly throughout the wearing course.

As in the case of macadam pavements, a bituminous pavement requires continuous maintenance. A slight depression formed on the surface of the road will rapidly enlarge, collect water and allow it to penetrate to the foundation, and will ultimately result in the disintegration of the road. These conditions do not result as rapidly in bituminous pavements as in the ordinary water bound macadam type, as the bituminous binder is more or less water proof, and furnishes a tougher and more lasting bond for the stones.

Bituminous pavements were not designed for heavy traffic. The bearing power of such a road is not great and therefore can not support heavy wheel loads. Neither does it give good results under voluminous horse-drawn traffic of a light character, as the surface is not hard enough, and the iron shod horses and steel tired wheels leave their impression upon the surface. This is especially true of a bituminous pavement in warm weather, when the surface may become so soft that even rubber tires of automobiles will leave their tracks.

This pavement is not greatly effected by automobile traffic. The surface bitumen however is subjected to evaporation caused by the sun and air, and is also effected by the decomposing action of rainwater. For these reasons it finally loses its binding qualities, and at the end of two or three years the pavement may require a new coat of bitumen. Where the question is one of economy, such a pavement is smooth, easily cleaned, and practically noiseless under horse drawn traffic. For these reasons, it may be well adapted for residential districts, and for streets largely

used for pleasure and high speed driving. Under these conditions and with adequate maintenance it may have a life of at least ten years.

The first cost of this pavement with a concrete base four inches thick and a wearing surface two inches thick, constructed by the mixing method, is estimated at $2.00 per square yard. The cost of renewal at the end of each period of ten years is estimated at $1.00 per square yard.

Assumed period	40 years.
Assumed life of pavement	10 years.
Assumed life of bonds 10 years at 4%.	
Assumed first cost of pavement $2.00 per square yard.	
Assumed cost of renewal - $1.00 per square yard.	
Guaranty period five years - four times.	
Interest first bond issue (.04 by 2.00 by 10) is	$0.8000
Sinking fund first bond issue (.08524 by 2.00 by 10) is	1.7048
Interest 2nd, 3rd, and 4th bond issue (.04 by 1.00 by 10 by 3) is	1.2000
Sinking fund to retire 2nd, 3rd, and 4th bond issues (.08524 by 1.00 by 10 by 3) is	2.5572
Cost of ordinary repairs (.12 by 20) is	2.4000
Total cost for 40 years per Sq. Yd. is	$8.6620
Total cost for 1 year per Sq. Yd. is	0.2166

-Construction of Bituminous Macadam by the Penetration Method.

Hot bitumen being poured over the top course stone. On Trunk Line road from Rockland to Rockport, Me., 1910.

·Construction of Bituminous Macadam by the Mixing Method.

Hot bitumen is mixed with the top course stone (also heated) before it is placed on the road. Ithaca, N. Y., 1909. Both of the above views are of experimental roads built under the supervision of the Office of Public Roads.

Tar Macadam. Spreading from distributing wagon by steam pressure furnished from steam roller. Rate of distribution, 600 gallons per half hour. It is possible to get more uniform spreading by this method than with hand cans.

Bituminous Macadam Under Construction by the Penetration Method at Ithaca, N. Y., 1909.

Tar Macadam. Two course treatment. West Cross street experimental work. Mt. Sterling, Brown County. Built 1909.

Illinois.

Mount Pleasant Cemetery, Toronto, Ont.
Roads constructed with Tarvia X.

Seeley Ave., Chicago, Ill.
Treated with Tarvia A.

CHAPTER 9.

CONCRETE PAVEMENTS.

Concrete has been used for many years as the base or foundation for pavements, but it is only within comparatively recent years that this material has been used as the wearing course.

In 1890 wide concrete gutters were laid in Bellefontaine, Ohio. These gutters were wide enough to serve as a pavement next to the curb, and as their surface was very smooth, most of the traffic was driven over them. After several years of such usage, the concrete showed very slight wear, with no cost for maintenance. This decided the City Engineer to experiment with concrete for street paving, and in 1893 two narrow streets were entirely constructed with concrete. The foundation consisted of a four-inch course of portland cement concrete, and the wearing course of a 1:1 mixture of portland cement and clean coarse sand. The pavements were laid in strips five feet wide, and then each strip was cut into blocks five feet square. This was the only provision made for expansion. After 18 years of service, these pavements were in comparatively good condition, with the exception of wear along the longitudinal joints. The cost of maintenance during this long period was practically nothing. The only objections to these pavements were that in wet weather their surfaces became slippery, due to the exceptionally rich mixture used in the wearing course.

Since 1900 a large amount of concrete pavements have been laid throughout the country, and improvements have been made in details of construction. There are now two characteristic types of concrete pavements. They are, pavement constructed entirely of concrete, and those constructed with a concrete base and a thin

wearing surface of bitumen and sand.

In the construction of both of these types of concrete pavements, a sub-base is first prepared. It consists of a six-inch course of cinders, slag, or broken stone, thoroughly rolled into place. The concrete pavement may be placed in two separate courses, or simply in one course. In both cases a six-inch concrete base is deposited upon the prepared sub-base; and if this is to act as the wearing course, it is tamped until the mortar flushes to the surface, and allowed to harden. Just before hardening takes place, the wearing surface is finished with a wood float, and roughened with a stiff broom. In two course construction, a wearing surface from one and one half to two inches thick, composed of one part cement to one and one half parts sand, is deposited upon the concrete base before it begins to set. Just before this surface hardens, it is finished with a wood float, and roughened by a stiff broom. Expansion joints are necessary for concrete pavements. They should extend through the entire thickness of the pavement. Longitudinal joints are usually placed next to the curb, and transverse joints should occur in every twenty-five to fifty feet.

If a wearing surface of bitumen and sand is to be placed upon a concrete pavement, after the concrete has hardened the surface is covered with hot bitumen applied with a sprinkler. The bitumen is then evenly spread over the surface by brushing with brooms, and covered with a layer of clean sand. The advantages of this covering is that noise is greatly reduced, and a soft cushion is formed, making travel easier for horses.

Concrete pavements are not effected by automobile traffic. They are not adapted to the heaviest traffic of our city streets as the resistance to crushing of concrete is not great enough.

A concrete pavement is easily cleaned, and not more slippery than are brick or stone block pavements. Its resistance to traffic is slight. It is a comparatively quiet pavement under horse-drawn traffic, due to its smoothness, and when covered with bitumen and sand it is rendered practically noiseless.

Concrete pavements are best adapted for the paving of rural highways, residence streets, pleasure drives, alleys, courts, and squares.

When properly constructed with suitable materials, concrete pavements are extremely economical. Their first cost is comparatively low, and they form a pavement that is permanent with a very low cost for maintenance.

The first cost of this pavement with a six inch concrete base, and wearing surface two inches thick of portland cement and sand, is estimated at $2.25 per square yard. The cost of renewal at the end of each period of ten years is $1.00 per square yard.

Assumed period 10 years.

Assumed life of pavement 10 years.

Assumed life of base 40 years.

Assumed life of bonds 10 years at 4 %.

Assumed first cost of pavement $2.25 per square yard.

Assumed cost of renewing pavement $1.00 per square yard.

Assumed cost of ordinary repairs $.04 per square yard.

Interest first bond issue (.04 by 2.25 by 10) is $0.9000

Sinking fund first bond issue (.08524 by 2.25 by 10) is 1.9170

Interest 2nd, 3rd, and 4th bond issues (.04 by 1.00 by 10 by 3) is 1.2000

Sinking fund 2nd, 3rd, and 4th bond issues

(.08524 by 1.00 by 10 by 3) is	\$2.5600
Cost of ordinary repairs (.04 by 20) is	.8000
Total cost per square yard for 40 years	\$7.3770
Total cost for one year per square yard	0.1850

Oil Concrete Pavements: Another type of pavement which has been developed only recently, is known as oil-cement-concrete paving, and is composed of a mixture of petroleum residuum with portland cement concrete. The oil is for the purpose of waterproofing the concrete, reducing its tendency to crack by contraction, and to prevent spalling under impact. Such a pavement is still in its experimental stage, and the outcome of these experiments will be watched by engineers with great interest.

Below, one of the Wayne County, Mich., roads in its former state. Above, the same highway after being paved with concrete.

Concrete Rural Pavement, Wayne County, Mich.

East Main Street, Eldora, Iowa

Ohio Street, between Sinclair Street and Lake Front, Chicago, Laid 1907-08.

Briggs Court, Grand Rapids, Mich.

Oakley Court, Grand Rapids, Mich.

Concrete Pavement, Fifth Ave., Gary, Ind.

Jefferson Street, Eldora, Iowa

Concrete Pavement with "Dolarway" Surface, Central Park, New York City

CONCLUSION.

From a study of the various forms of road construction, it is evident that but little difficulty is experienced in constructing durable and satisfactory roads. Roads may be built to withstand motor traffic, and also to withstand horse traffic; and if either kind of traffic occurs separately, the problem is greatly simplified. A combination of the two classes of traffic, where one or both are heavy, and unfortunately this is the usual condition, renders the problem more difficult. But even in this case it is possible from a structural standpoint, to construct roads for this mixed traffic. However, it is necessary at the present day to consider the problem as an economic one, and it is with this end in view that pavements should be considered.

The selection of the proper pavement in any case is a problem requiring skill, good judgment, economic knowledge, and an analysis of the local conditions. Several important factors must be considered, among these being the quantity and nature of traffic, the character and nature of the district through which the pavement is to built, and the qualities of the pavements as to durability, smoothness, noiselessness, slipperiness, sanitary qualities, and economy.

The annual cost, estimated life, and first cost per square yard of the different pavements are here given, as an aid in the selection of the pavement best suited to local conditions.

SEE FOLLOWING PAGE FOR TABLE.

Estimated Life and Cost of Various Pavements.

Traffic	Pavement	Life Years.	1st cost per sq. yd.	Annual cost per sq. yd.
	Earth	00	$0.043	$.0000
Light-Rural	Gravel	10	0.500	.1076
Light-Rural	Macadam	10	1.000	.1790
Heavy-City	Granite Block	40	3.500	.1145
Medium-Highway	Brick	40	2.250	.0755
Heavy-City	Wood Block	15	3.750	.2797
Medium-City	Asphalt	10	2.800	.3640
Medium-Parkways	Bituminous	10	2.000	.2166
Medium-Highway	Concrete	10	2.250	.1850

The paving of city streets will first be considered. For this purpose a pavement must be selected that is permanent and economic under such city traffic as may come upon it. If a pavement is selected which is not durable under such traffic, the maintenance cost will rapidly increase, and cause the annual cost to rise beyond economic bounds. None of our modern pavements suitable for city streets are effected by automobile traffic, therefore this side of the question need not be considered. When traffic is excessively heavy and voluminous, the modern granite block pavement is found to be both economic and durable. It is however very noisy. For pavements laid in congested business districts, where there are office buildings and retail stores, it may be found necessary to reduce the noise; and in such cases, it may be advisable even at an increased annual cost, to adopt a wood block pavement. Where traffic is less congested, a brick, asphalt, or cement pavement may be used. Brick will support heavier traffic than either asphalt or concrete, it being claimed by paving brick manufacturers that this pavement is suited to the heaviest city traffic. Asphalt may be used where traffic is of a continuous nature and medium in weight. Cement pavements have not been in use for a period long enough to warrant a statement as to what kind of traffic conditions they are best suited for. As seen from the

table, cement forms a very economic pavement when traffic is fairly light in weight and amount. It may safely be said that cement can not support as heavy traffic as can brick.

All city pavements are sanitary, some slightly more so than others.

In the paving of highways, gravel and broken stone have proved to be a failure under automobile traffic; and except on roads used mostly by light horse drawn vehicles, these pavements should never be laid. Where good pavements of this nature already exist, it may be economical to prolong their life by a surface application of bituminous binder. A bituminous pavement is noiseless, dustless, and sanitary; and although it is not an economical form of construction, it may be preferable to other pavements for highways subjected mostly to automobile traffic, as is the case on parkways, boulevards, and pleasure drives. A great many of our highways must be constructed to meet the requirements imposed upon them by moderately heavy wagon traffic, heavy motor truck traffic, ~~traffic~~, and automobile traffic. Any city pavement can successfully meet these requirements, but in most cases their first cost is prohibitive. There are at the present day but two forms of modern pavements which may be economically used for high way construction, and they are the concrete and brick pavements. The first cost of either concrete or brick paving is comparatively low, although higher than macadam; and as can be seen from their annual cost, they are very economical. Concrete may be used for moderate traffic. Brick should be used for highway paving where traffic is of the heaviest nature. Both of these pavements are durable, smooth, sanitary, not excessively noisy; and it would appear that in the construction of such pavements for our highways lies the solution of the good roads question.